Ground Based Operational Testing of Holographic Scanning Lidars: The HOLO Experiments

GEARY K. SCHWEMMER
Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771
THOMAS D. WILKERSON, JASON A. SANDERS
Utah State University, 1695 North Research Park Way, Logan, Utah 84341
DAVID V. GUERRA
Saint Anselm College, Manchester, New Hampshire 03102
DAVID O. MILLER
Science Systems and Applications, Inc., Greenbelt, Maryland 20771
STEPHEN E. MOODY
Orca Photonic Systems, Inc., Redmond, Washington 98052

ABSTRACT

Two aerosol backscatter lidar measurement campaigns were conducted using holographic scanning and zenith staring lidars for the purposes of reliability testing under field conditions three new lidar systems and to develop new scanning measurement techniques. Particularly intriguing is the possibility of deriving atmospheric wind profiles from temporal analysis of aerosol backscatter spatial structure obtained by conical scan without the use of Doppler techniques.

1. Introduction

Two one-week intensive measurement campaigns, named HOLO-1 and HOLO-2, were conducted to evaluate three new lidar instruments in an operational mode typical of scientific field investigations, and to develop new data analysis algorithms for scanning lidar applications. HOLO-1 was conducted 7-13 March, 1999 at the Space Dynamics Laboratory in Logan Utah. HOLO-2 was conducted 5-12 June, 1999 at Saint Anselm College in Manchester, New Hampshire. Instruments included in both experiments were the Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE), the Army Research Office Lidar (AROL-2), and a wide-angle visible CCD camera (Skycam) with a video tape recorder. The Prototype Holographic Atmospheric Scanner for Environmental Remote Sensing (PHASERS) permanently installed at Saint Anselm College was used in addition to these instruments during HOLO-2.

2. Background

NASA's long range interest in holographic scanning lidars stems from the necessity to develop lightweight, large aperture, scanning telescopes for use in space. For many types of scanning lidar telescopes, a simple rotating disc containing a holographic optical element (HOE) will be able to replace the heavy and complex scanning systems that have had to be used in the past. NASA's Small Business Innovative Research and Cross Cutting Technology Programs have supported HOE lidar developments for this purpose.

PHASERS was the first holographic scanning lidar, and is based on a 40 cm reflection HOE that works with the second harmonic of a Nd:YAG laser. Designed in the early nineties (Schwemmer and Wilkerson, 1992) saw first light in 1995 at the (then) Goddard Optical Research Facility (Schwemmer, et.al., 1996). It has since undergone several transformations and now resides in an observatory on the roof of the Science Center at St. Anselm. Currently the original HOE made in 1991 is still employed as the primary optic for the system.

HARLIE is an airborne aerosol lidar based on a 40 cm transmission HOE that works with the Nd:YAG fundamental wavelength at 1064 nm (Schwemmer, 1998). It was completed in December 1997 and flown in a series of short test flights in the spring of 1998. A dolly was made for supporting HARLIE on the ground and allows it to be held in any of eight positions spaced 45° apart on trunions attached to the side of the instrument. For ground based measurements it is normally used with the rotation axis pointing to zenith with the HOE sweeping out a 90° (full angle) cone where the FOV is always at 45° elevation. With the axis tilted at 45°, the scan will sweep out a cone with one edge on the horizontal and another on the vertical. HARLIE uses a 2 mJ, 5kHz pulsed YAG with a single Geiger-mode avalanche photodiode detector. It has two ping-ponged scalar units to avoid any dead-time due to data readout.

AROL-2 is a portable ground based zenith-only viewing lidar using a 100mJ, 20 Hz pulsed 2xNd:YAG laser transmitter. It has an analog and a photon counting photomultiplier detectors for each of its parallel and cross-polarized receiver channels. AROL-2 was the only hermetically enclosed instrument in the campaign, but it was usually moved in-doors during periods of precipitation along with the rest of the instruments.

3. Objectives

The primary objectives of the HOLO campaigns were technology oriented, to test the hardware and its measurement characteristics in the field, and to develop new and better data analysis algorithms prior to committing them to any scientific field investigations. In addition, we wanted to develop a new application for conically scanned cloud and aerosol lidars: atmospheric wind profiling using aerosol structure correlation methods. The following is a list of the HOLO objectives.

a. Technology Objectives

1) Evaluate the lidars' response to a variety of aerosol and cloud loading conditions, both in daytime and nighttime to assess any improvements to the performance that may be needed to derive various atmospheric parameters. For example: cloud bottom height, boundary layer height, aerosol backscatter coefficient profiles, and cross-scan correlation wind profiles.

2) Test HARLIE's response as above for a variety of laser pulse energy levels to determine the optimum operating energy given the detector response, both for day and night measurements.

3) Acquire sufficiently long data records to use in developing cross-scan correlation wind profile algorithms.

b. Science Objectives

1) Determine local boundary layer dynamics scenarios by observing aerosol and cloud backscatter profiles with scanning and zenith pointing lidars and visual cloud fields with a wide field camera.

2) Prepare for CASES campaign by observing the transition from a convective boundary layer (CBL) to a nocturnal boundary layer (NBL) and back.

3) Look for gravity waves and currents, low level jets, in both the NBL and CBL data, to document and evaluate the importance and frequency of occurrence of these events.

4) Generate statistics on the scales of atmospheric aerosol and cloud structure and motions in order to refine measurement approaches (e.g. scan rates, averaging times, bin sizes, etc.) for future observations.

4. Synopsis of HOLO-1

Logan is situated on the east side of Cache Valley in northern Utah, about 100 km north of Salt Lake City. Cache Valley runs about 90 km north to south, bisected by the Bear River and is approximately 15 km east to west near Logan. The river is dammed to form Cutler Reservoir (normal water level 1343 m above mean sea level [ASL]) located several km northwest of Logan. The Space Dynamics Lab sits at the foot of the Wasatch Mountain Range that forms the east wall of the valley, containing peaks up to about 2700 m elevation ASL. This environment presented us with a variety of meteorological conditions, cloud types, and aerosol loading during the week of the campaign. The equipment was arranged on the roof of the Jake Garn Bldg. in Research Park at an elevation of 1387 m giving us an unobstructed view over the 90° cone of the scanning lidar and a west-east transect of Cache Valley (Fig. 1).

FIG. 1. Western view across Cache Valley from the roof of the Jake Garn Building showing the arrangment of HARLIE (black boxes) and AROL-2 (white box).

The week began dominated by a trof presenting us with a series of squall lines with mixed precipitation for the first 3 days, followed by a cold front early on the evening of 9 March from 1930-2400MT. Abundant clouds followed this on the 10th from another trof developing in southern Utah and Arizona pulling moist air from the California Baha. These were pushed out by a high pressure air mass giving us clear skies on the last two days of the experiment. Air temperatures were moderate during the week of HOLO-1, with daytime highs ranging from –2 to +6 °C and night time lows from –6 to –1 °C.

We operated HARLIE with the rotation axis vertical from 7 March through noon on 12 March. HARLIE was first set to scan at approximately 1 revolution every 7.2 seconds, or 50°/sec and to record a profile every 100 ms. Laser energy was varied between 2 and 20 watts average power. No saturation, other than minor pulse pile up effects, were seen in the data and no adverse effects to the HOE were noted at any laser energy. Later, on 9 March, the scan rate was slowed to 10°/sec to provide higher angular resolution. On the coldest nights frost formed on the HOE except over the center portion illuminated by the outgoing laser beam. Heaters were added to the instrument following HOLO-1 to alleviate this problem. Occasional laser dropouts occurred periodically during both HOLO campaigns due to problems with the laser power supply system. Around 0630 MT on 12 March we redirected HARLIE so the scan axis was oriented at 45° elevation angle, and aimed 23.8° north of due west. In this manner the beam would point horizontally on one part of the scan, and point at zenith on the opposite side of the scan. We did this to observe boundary layer dynamics across the valley with high vertical resolution. The beam intersected the base of Box Elder Peak at the opposite side of the valley. Figure 2 is an example of this “Tilt-Scan” mode data. The bright line of return signals at 15-30 km range between 340° and 5° scan angles, are ground returns from the west side of Cache Valley. Laminar aerosol layers form parabolas when the tilt-scan data are rendered on rectilinear plot axis in this fashion.

At 0730 on 13 March, we stopped scanning and positioned the scanner to point the laser at an 11.31° elevation angle, (a slope of 1/5), and pointing roughly due west to observe the growth of the boundary layer over the valley from sunrise to full noon.

AROL-2 was programmed to record a profile typically every 30 seconds. The Skycam, which has a 75° full angle field of view, was oriented parallel to the HARLIE scan axis, with the top of the camera image toward due north.

5. Synopsis of HOLO-2

HOLO-2 presented us with a very different environment. Saint Anselm College is set in rolling terrain on the west side of Manchester, New Hampshire and approximately 153 km south of the White Mountains at an elevation of 134 m ASL. HARLIE, AROL-2, and Skycam were located in a field at a small astronomical observatory controlled by the college, about 1 km West of the campus and the PHASERS installation on top of the Science Center (Figs. 3,4)

The first couple of days were quite windy with very high aerosol loading by large and abrasive pollen from the many local conifers. The remainder of the week continued warm, with decreased aerosol loading, and a small weather system delivering light showers passing through on June ____. The day time highs ranged from 39°C at 1300 ET on 7 June to 19°C at 1300 ET on 9 June. The night time lows ranged from 24°C at 0500 ET on 8 June to 8°C at 0200 ET on 11 June.

6. Conclusions

All three lidar systems operated about 50-70% of the time, with much of the down time being due to precipitation, the occasional operator error, and for short periods of rest and relaxation. Very little down time was due to instrument malfunctions, although we were not spared these. Either of the mobile systems, AROL-2 and HARLIE, are rugged and reliable enough to be used in field missions with a high certainty of meeting investigators’ commitments and objectives. The scanning data is very useful in helping with three-dimensional visualization of atmospheric dynamics, and the prospect of obtaining vertical wind profiles from an ordinary backscatter lidar by non-Doppler methods appears to hold much promise in many applications

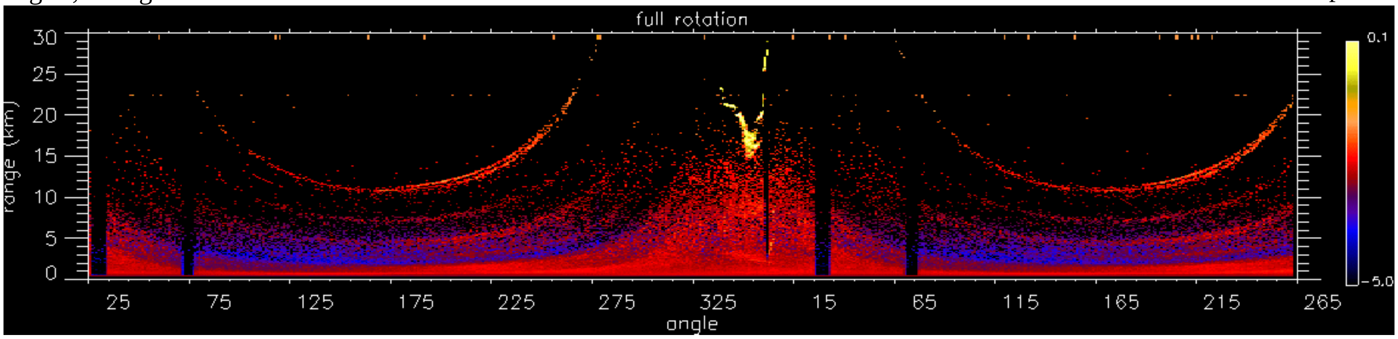

FIG. 2. An example of "Tilt-Scan" mode HARLIE data, with profiles varying from the horizontal at 0°, to the vertical at 180°.

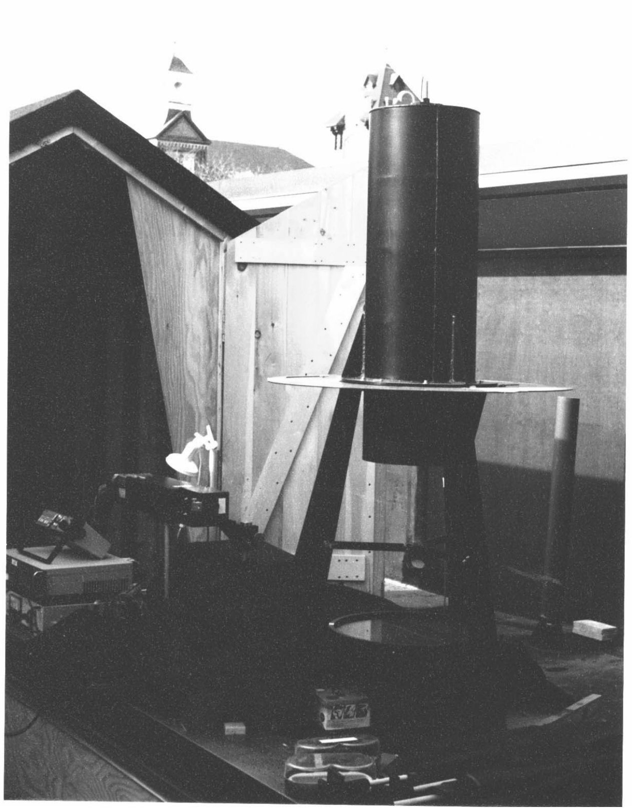

FIG. 3. Photograph of the PHASERS lidar system on the roof of the Science Center, Saint Anselm College in Manchester, New Hampshire.

where aerosol and cloud structure can be relied upon to yield a measurement. More detailed results on these individual topics are presented in three companion papers to this overview.

7. Acknowledgments

The authors wish to express thanks to the support of the

FIG. 4. The observatory at Saint Anselm College. HARLIE and AROL-2 are located in the half-walled deck area between the building and the truck.

NASA Cross-Cutting Technology and SBIR Programs, Space Dynamics Laboratory (USU), and the Army Research Office Programs for supporting this work. We also wish to acknowledge the efforts of Jeffrey Schnick, James McLain and Adele Maurierin for helping with HOLO-2 operations.

REFERENCES

Guerra, David V., Albert D. Wooten, Sandipan S. Chaudhuri, Geary K. Schwemmer, Thomas D. Wilkerson, (1999). Prototype Atmospheric Scanner for Environmental Remote Sensing, *J. Geophys. Research*, **104**, No. D18, 22,287-22,292.

Schwemmer, Geary K., and Thomas D. Wilkerson, (1992). Conically Scanned Lidar Telescopes using Holographic Optical Elements, *Sixteenth International Laser Radar Conference, Proc., 20-24 July 1992, Cambridge, Mass.*, NASA CP-3158/PT2, 521-524.

Schwemmer, G., (1993). Conically Scanned Holographic Lidar Telescope, *U.S. Patent No. 5,255,065*, Oct. 1993.

Schwemmer, Geary K., D. Barry Coyle, David V. Guerra, (1996), Holographic, Solid State Atmospheric Lidar, *Proc., Lasers '95, Dec. 4-8, 1995, Charleston, SC,* STS Press, McLean, VA, 714-717.

Schwemmer, G. K., (1998). Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE), *Nineteenth International Laser Radar Conference, Proc., 6-10 July 1998, Annapolis MD,* NASA/CP-1998-207671/PT2, 623-626.